

Improving the Navy's Passive Underwater Acoustic Monitoring of Marine Mammal Populations

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LONG-TERM GOALS

The long-term goals of this research effort are to improve the Navy's passive underwater acoustic monitoring of marine mammal populations. A major focus in this project is on further enhancing the ability to estimate environmentally-calibrated calling density (calls per unit area per unit time) obtained from raw detections of calls in underwater acoustic recordings. The efforts in this program also will support the Ph.D. research of a graduate student in marine bioacoustics and ocean acoustics at the Scripps Institution of Oceanography.

OBJECTIVES

The specific objectives of this project are: 1) to further develop the methods for accurately estimating the densities of low-frequency-calling marine mammal species using passive acoustic monitoring, with application to obtaining density estimates of transiting humpback whale populations in the Southern California (SoCal) Bight, 2) to incorporate detection theory formalism into the acoustic density estimation procedure in order to minimize the variance of the density estimates, 3) to apply the numerical modeling methods for humpback whale vocalizations to understand distortions caused by propagation of humpback calls west of Kauai, Hawaii, and 4) to conduct spatial statistical analyses and correlation analyses of marine mammal and other bioacoustic sounds in the SoCal Bight with man-made underwater sounds, with physical properties of the environment, and with fields relevant to the biological productivity of the water column. The work in this project is heavily leveraged with other ongoing programs and efforts, as discussed in Related Projects below.

APPROACH

The overall approach being used in this project is to extend the research thrust of correcting for environmental properties in detections of marine mammal calls in passive underwater acoustic recordings, and to use these environmentally-corrected call detections to learn more about the animals themselves. Detected call counts are determined not only by the animals' calling characteristics, but also by the properties of the underwater environment in which the calls are recorded. First,

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propagation through the ocean environment can have a significant distorting effect on the recorded calls. This distortion can be strongly site dependent and dependent upon time of day and season. Second, the sounds from all other sources in the ocean (“noise”) directly affect the ability to detect calls of interest. The characteristics and level of noise also can be strongly dependent upon recording location and time. By correcting the detected call counts for these environmental effects, along with assigning uncertainty to the resulting environmentally-calibrated call density estimates, scientifically meaningful conclusions about the calling characteristics of the whales themselves can be obtained. Much of the foundation for the work being done in this project was developed during Tyler Helble’s Ph.D. thesis research.

The specific approach being followed to accomplish objectives 1-4 above is listed below.

1) Detailed numerical modeling of humpback whale call propagation (as in Helble et al., 2013a) will be conducted at a number of “High-frequency Acoustic Recording Package” (HARP) monitoring sites off the California coast (Fig. 1). The low-frequency content of these animals’ calls makes it imperative to account for the frequency-dependent, complex waveguide effects in call propagation. The best available water column and ocean bottom archival information presently is being assembled to support this modeling effort. The C version of the Range-dependent Acoustic Model (“CRAM”), a parabolic equation-based numerical model developed by Richard Campbell and Kevin Heaney, will continue to be used since the code authors have optimized it for numerical efficiency. One goal of this numerical modeling will be to determine the appropriate frequency spacing required for synthesizing the humpback calls in the time domain. (In previous work, the frequency spacing of 0.25 Hz was much smaller than that required to accurately synthesize the humpback call waveforms). Another goal will be to extend the modeling to source-receiver ranges greater than 20 km in certain situations where efficient long range propagation can occur (e.g., at Hoke Seamount). Humpback calls will be detected in the HARP data collected at these sites using the Generalized Power Law (GPL) detector (Helble et al., 2012) and the resulting call counts will be calibrated for environmental effects using the estimated probability of detection (re Helble et al., 2013a,b). The corresponding statistical uncertainties of the calibrated call densities also will be calculated. These calibrated call density estimates then can be converted into animal density estimates, through normalization by an estimate of the average call (cue) rate (Marques et al., 2009). This work will be coordinated with Tyler Helble’s project “Obtaining Cue Rate Estimates for Some Mysticete Species using Existing Data” in order to use the best available humpback call rate estimates.

2) A main component of incorporating detection theory formalism into the acoustic density estimation procedure was completed earlier this year, before the funds for this project were received. The results have been included in Helble et al., 2013c.

3) Detailed numerical modeling will be conducted of the propagation of humpback whale vocalizations originating in the shallow water reef areas just west of Kauai, Hawaii to the Pacific Missile Range Facility (PMRF) hydrophones in deeper water offshore (re Fig. 2). The approach will follow that in 1) above. The goal will be to understand the distortions caused by propagation to determine whether or not they can be used to help localize the calling animals. Application of waveguide invariant methods will be investigated as part of this effort. Propagation distortions will be particularly strong over the shallow portion of the path, the biogenic reef off fringing Kauai. The sediments in this region are a composite of coarse-grained carbonate and fine-grained volcanic sediments (Fig. 2b) that are poorly sorted compared to the well sorted, fine-grained quartz sediments of terrigenous origin often found in other shallow water environments.

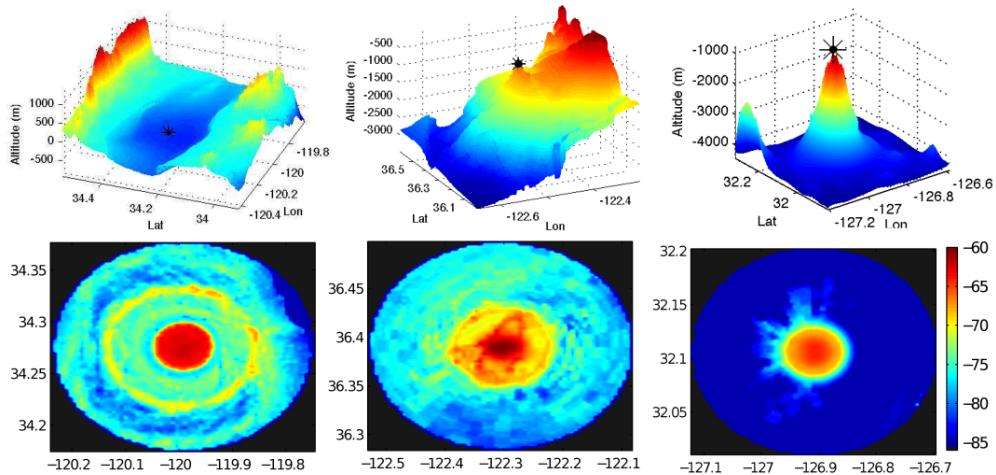


Figure 1. Upper row of plots show the bathymetry at three HARP passive acoustic monitoring sites: (left to right) Santa Barbara Channel, Sur Ridge, and Hoke Seamount, with the HARP location marked with a black asterisk. The corresponding transmission loss (TL) plots for each site, incoherently averaged over 50 Hz to 1800 Hz, are plotted in the lower row, with the color scale for TL (dB) displayed in the lower right.

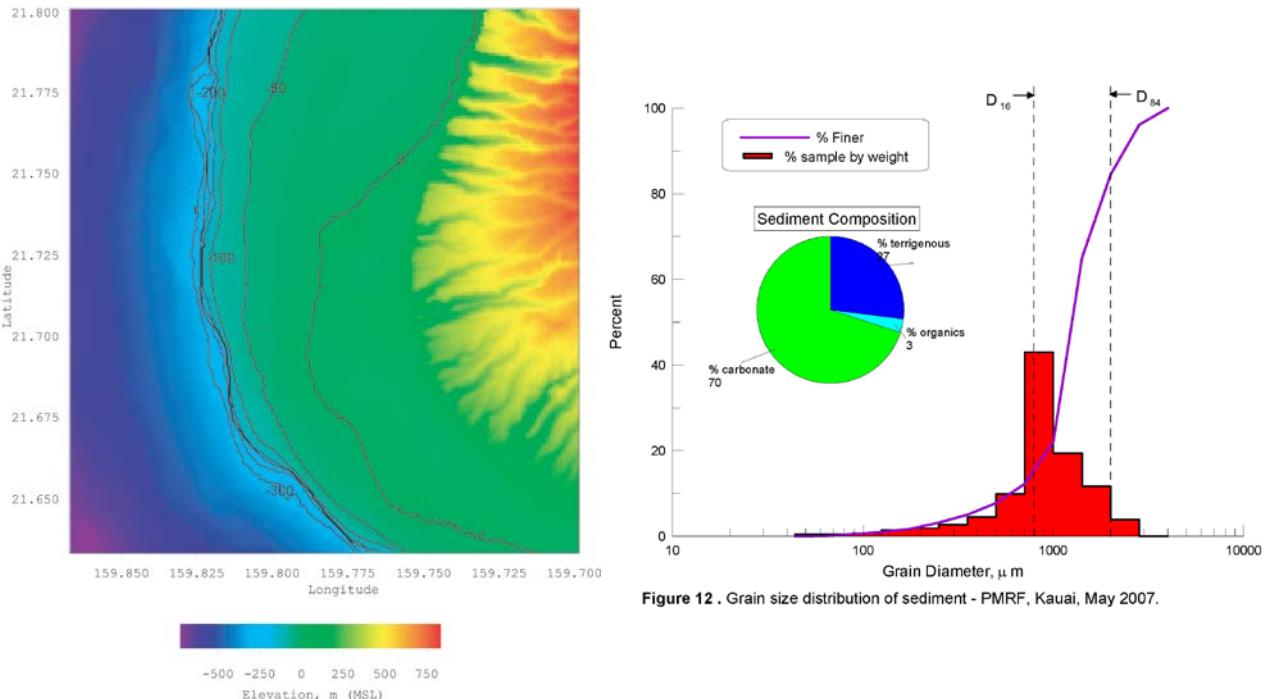


Figure 2. (Left) The bathymetry west of Kauai derived from the National Ocean Survey (NOS) digital database (depth contours in meters MSL), and (Right) the sediment grain size distribution at PMRF.

4) New methods of spatial and spatiotemporal statistical analyses and spatial correlation analyses will be applied to marine mammal and other bioacoustic sounds in the Southern California Bight. These statistical procedures hold significant promise for identifying patterns they may have biological significance and for providing new information on marine mammal behavior. Spatial correlations with man-made underwater sounds, with physical properties of the environment, and with fields relevant to

the biological productivity of the water column also will be conducted. Since much of the software to perform these analyses already exists, the approach to achieve this objective involves mostly the collection of the relevant data bases. This effort also likely will involve acoustic localization of marine mammal calls using a data set collected off the southern California coast in 1999.

One graduate student who will be working in this project has just started her first year in the Applied Ocean Sciences curricular group. She comes to Scripps with bachelor's and master's degrees in electrical engineering. As the recipient of a Regents Fellowship, awarded to the most promising first year student in each curricular group at Scripps Institution of Oceanography, she comes at no cost to the program the first year. Her initial research focus is on modifying and using the GPL detector, and comparing its performance to matched-filter-based detectors, for detecting and classifying transient sounds of biological origin. The GPL detector is based on a power-law processor, which is the optimal detector for transient signals when no *a priori* knowledge of the arriving signal exists. The family of power-law processors includes the energy detector. However, for stereotyped calls where propagation effects are not too strong, a matched-filter-based detector may have better performance.

The work in this project was leveraged with other ongoing programs, listed in Related Projects below.

WORK COMPLETED

The funding for the first year of this project arrived in house at the end of August, 2013. Therefore, the project has only been in existence for a month or so, and work has only just started.

The first step was to acquire a modern workstation to perform the computationally intensive acoustic propagation modeling and data analysis. All necessary software to perform the research in this program now has been installed on this computer.

To support the numerical modeling, data bases of environmental properties are being identified and accessed for the relevant information. The focus of this effort is on acquiring the data necessary to create geoacoustic models of the ocean bottom/sub-bottom using Hamilton's empirical equations (Hamilton, 1980). Although few areas in the Southern California Bight have been well studied, and useful information on the ocean bottom is readily available, the uncertainty in the geoacoustic properties will be largest source of uncertainty in the propagation modeling.

As mentioned under Approach above, a major part of the effort at incorporating statistical detection theory into animal density estimation from passive acoustic recordings already has been completed.

An effort has been started on examining the statistics of animal call distributions in space and time. A few initial results are presented in the next section.

Finally, two peer-reviewed papers have appeared in print, one in the September, 2013 special issue of the Journal of the Acoustical Society of America (Helble et al., 2013a) and the second one in the October, 2013 issue of JASA Express Letters (Helble et al., 2013b). A third paper, to Endangered Species Research, is nearly ready for submission (Helble et al., 2013c). In addition, two presentations were given at the June, 2013 "Detection, Classification, Localization, and Density Estimation" workshop in St. Andrews, Scotland (D'Spain et al., 2013; Helble et al., 2013d).

RESULTS

As mentioned above, the funding for this project arrived 30 August, 2013. Therefore, only a few steps have been taken to date. The efforts in this program are a continuation and extension of the work performed in previous projects. Most of the results from those efforts appear in Helble et al., 2012, 2013a-c and will not be repeated here. Only results from mid-summer, 2013 to present are listed below.

- To achieve optimal performance in those cases where results are not required in real time, the detector threshold should be set so that all humanly detectable calls are detected by the autonomous processor. Trained analysts then can examine the resulting detections to eliminate any false detections, reducing the probability of false alarm to effectively zero. This approach provides human-level detection and classification performance while reducing the human work load by a significant amount (an amount that depends upon the percentage of uninteresting data that the autonomous detector is able to winnow out from consideration). Setting the detector threshold at a higher level in order to reduce the uncertainty in the estimated probability of detection does not help reduce the overall uncertainty in the environmentally-calibrated call detection estimates. The reason is that raising this threshold introduces a non-zero probability of false alarm which then introduces its associated uncertainty;
- The spatial distribution of locations of calling animals during one experiment display statistically significant clustering for all call types using the nearest neighbor test. One call type shows significantly greater clustering than other call types. These results may reflect a behavioral context for this call type (e.g., call/counter-calling between a mother/calf pair).

IMPACT/APPLICATIONS

Passive underwater acoustic monitoring of marine mammal sounds is the Navy's primary method for characterizing the presence, distribution, and number of marine mammal species in a wide variety of environments, particularly those associated with Navy training ranges. Marine mammal population density estimates are particularly important in regions of Navy activities, or potential activities, in order to properly evaluate their potential impact under federal environmental legislation.

Understanding, and improving, this passive acoustic monitoring capability will decrease the environmental risk of Navy training exercises and other activities. Both the southern California Bight region and the area west of Kauai are areas of operational/training interest to the Navy. In addition, since these research efforts will involve a graduate student in the field of marine bioacoustics at the Scripps Institution of Oceanography, as part of the required thesis research, this project will help provide the Navy with the future generation of highly trained ocean bioacousticians aware of both Navy needs and environmental issues.

RELATED PROJECTS

The efforts in this project will be heavily leveraged with other programs. First, efforts in our Living Marine Resources project titled "Improving the Navy's Automated Methods for Passive Underwater Acoustic Monitoring of Marine Mammals" are focused on modifying the GPL processor for detecting a wide variety of marine mammal calls recorded by Navy range monitoring systems (the range hydrophones at the SCORE and PMRF ranges, and John Hildebrand's HARP packages in southern California), and environmentally calibrating the resulting detected call counts. Call rate estimates from Tyler Helble's project "Obtaining Cue Rate Estimates for Some Mysticete Species using Existing Data" will be used to derive animal density estimates from the calibrated call densities. The Regents

fellowship presently is covering graduate student costs. Participation by senior-class undergraduate students from the UCSD Environmental Engineering department was arranged by the UCSD Vice Chancellor of Academic Research. Algorithms from our “Glider-Based Passive Acoustic Monitoring Techniques in the Southern California Region”, Code 322-MBB, are used to automatically scan the data for marine mammal calls and other biological sounds.

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